Crustal Structure in Central Japan as Derived from the Inabu Quarry Blast Observations

By Akira IKAMI, Isao YAMADA, Hiroshi MURAKAMI, Nobuo HURUKAWA and Fumiaki TAKEUCHI

(Manuscript received March 31, 1977)

Abstract

On September 2, 1976, a 7.5 tons quarry blast was made at Inabu, in the northeastern part of Aichi Prefecture. The crustal structures along the two profiles in central Japan were investigated using the seismic waves generated by this quarry blast.

In travel time curves, there are gaps of about 0.5 sec and 0.3 sec. These travel time gaps may be attributable to the Median Tectonic Line and the Yoro Fault, and vertical offsets at these faults were calculated as 6.3 km and 5.3 km, respectively.

A granitic layer, which has been considered to have a velocity of about 6.0 km/sec, can actually be divided into two layers with velocities of 6.0 km/sec and 6.3 km/sec, and beneath these layers a basaltic layer exists with a velocity of 6.8-6.9 km/sec. There is no clear phase which shows the Pn velocity.

1. Introduction

The Research Group for Explosion Seismology (R. G. E. S.) in Japan has been carrying out the explosion experiments to investigate the Moho discontinuity. Several experiments were carried out in central Japan and crustal structures from those controlled experiments were determined by Sasaki et al.[1], Aoki et al.[2], Yoshii et al.[3] and Aoki and Muramatu[4].

To investigate the shallow structures in this area, we observed the quarry blast of 7.5 tons, which was made on September 2, 1976, at Inabu, in the northeastern part of Aichi Prefecture. Observations were operated by the members of Nagoya University, Kyoto University, Gifu University, Aichi Institute of Technology, Tokai University, and Aichi University of Education. Seismograms recorded at microearthquake and seismological observatories in the Kinki and the Chubu districts were also used in the analyses. Locations of the shot point and observation stations are shown in Fig. 1 and Table 1. These stations were placed in five regions such as; (1) the Kinki district, (2) the Mino (southern Gifu Prefecture) district, (3) the eastern Gifu district, (4) the Tohkai district and (5) the others. The data observed in five regions are listed in Table 2. Because of no temporal stations in the eastern Gifu district, there was no record with satisfactorily accurate time, so the crustal structure in this area could not be determined. As the crustal structures in the Kinki district and the Mino district are similar to each other, we discuss these two in the same section.

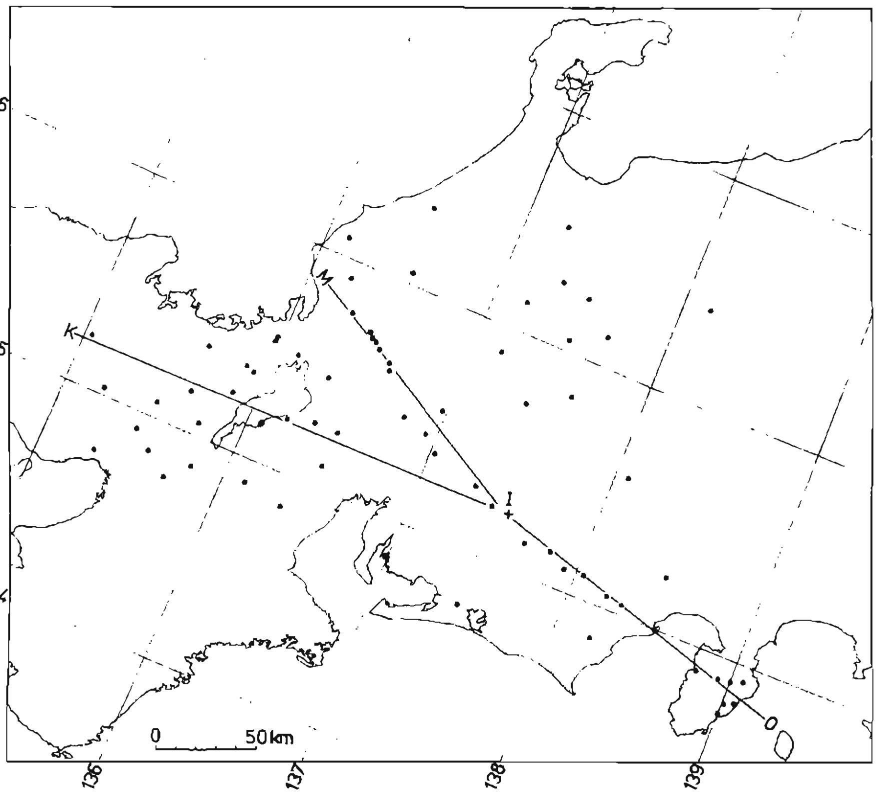

Fig. 1. Location of the shot point (+) and observation stations (●).

Table 1. Location of observing stations, azimuths, distances and observers.

Station No.	Code	Observation point	Latitude (N)	Longitude (E)	Height	Azimuth	Δ	Observers*
shot point								
		Inabu	35°13′33.4″	137°31′24.6″	615m		0.00km	A. Ikami, A. Tsuzuki, S. Kaede, T. Tsuboi
the Kinki district								
K 1	TAR	Tara	35 15 41.4	136 29 42.2	490	S 92.4°W	93.68	K. Ito
K 2	UGK	Ugakei	35 05 48.0	136 28 22.6	290	81.5	96.77	K. Saito
K 3	OCH	Ochiai	35 15 55.0	136 21 14.0	370	92.3	106.53	F. Takeuchi, S. Matsuo
K 4	AZJ	Azai	35 28 38.0	136 19 26.0	370	104.3	112.53	H. M. O.
K 5	KMY	Kameyama	34 52 01.2	136 21 00.0	240	69.6	114.22	I. S. O.
K 6	KJY	Kojinyama	35 13 51.9	136 11 59.4	265	90.3	120.49	Y. Umeda
K 7	OHM	Omihachiman	35 10 25.7	136 05 00.6	120	87.5	131.25	A. S. O.
K 8	ORJ	Oura	35 31 01.7	136 07 10.9	130	104.2	131.58	K. Mino, N. Hurukawa
K 9	MHJ	Mihama (T)**	35 31 50.2	135 58 44.2	260	103.5	144.34	H. M. O.
K 10	MHD	Mihama (D)**	35 33 25.5	135 58 54.6	110	104.7	144.78	H. M. O.
K 11	BHO	Bohmura	35 14 41.0	135 52 22.0	380	90.8	150.25	A. S. O.
K 12	UJI	Uji	34 51 59.8	135 49 36.7	290	75.6	159.83	A. S. O.
K 13	KGM	Kamigamo	35 03 33.5	135 45 56.7	180	83.4	161.22	A. S. O.
K 14	KHK	Keihoku	35 10 38.8	135 39 44.3	260	88.1	169.55	A. S. O.
K 15	YGI	Yagi	35 04 05.2	135 30 42.8	180	84.5	184.12	A. S. O.
K 16	TNJ	Tannan	35 01 54.2	135 12 50.9	310	84.2	211.56	A. S. O.
K 17	HMT	Hikami	35 13 35.5	135 02 36.6	250	90.0	225.74	T. M. O.
the Mino district								
M1	YHG	Yahagi	35 14 00.2	137 25 16.6	305	95.1	9.34	F. Kimata
M2	OOK	Ookawa	35 17 03.7	137 18 15.9	500	108.0	20.96	I. Yamada
M3	INU	Inuyama	35 20 58.8	137 01 02.8	132	107.0	47.06	I. S. O.
M4	UNM	Unuma	35 24 45.4	136 56 02.3	120	111.1	57.46	I. S. O.
M5	SPJ	Shinpukuji	35 27 13.5	136 47 34.7	65	110.8	71.05	I. S. O.

Station No.	Code	Observation point	Latitude (N)	Longitude (E)	Height	Azimuth	Δ	Observers*
M6	MDR	Midori	35°36′42.1″	136°37′08.6″	190m	S 117.5°W	92.61km	T. Baba, H. Tanaka
M7	OOI	Ooi	35 38 30.8	136 35 54.1	210	118.8	95.84	H. Ando
M8	AKT	Akatani	35 39 43.7	136 33 26.8	270	118.9	100.16	K. Sato
M9	UMS	Umasaka	35 40 32.4	136 31 12.0	550	118.7	103.86	T. Shinoda, T. Endo
M10	TKY	Tokuyama	35 41 36.3	136 29 07.2	310	118.8	107.56	R. Yokoyama, Y. Seto
M11	YMT	Yamate	35 42 30.2	136 27 14.8	330	118.9	110.83	Y. Sasaki, K. Fukumoto
M12	TKA	Tsuka	35 44 02.5	136 25 58.3	410	119.7	113.89	S. Fukuzawa
M13	IMJ	Imajo	35 47 53.4	136 18 10.0	240	119.8	127.63	H. M. O.
M14	KAJ	Katsuyama	36 02 55.2	136 31 41.3	30	135.4	128.28	H. M. O.
M15	HKJ	Hokuriku	35 56 15.0	136 12 45.0	20	123.6	142.64	H. M. O.
M16	KMJ	Komatsu	36 21 52.3	136 30 20.6	70	143.9	156.26	H. M. O.
M17	FKJ	Fukui	36 05 38.9	136 07 24.0	90	127.2	159.21	H. M. O.
the eastern Gifu district								
Y 1	KSM	Kashimo	35 42 42.3	137 22 57.7	640	166.7	55.39	K. C. M. O.
Y 2	MKD	Makio	35 49 20.8	137 36 16.9	850	-173.7	66.58	I. S. O.
Y 3	MID	Miura	35 49 19.1	137 23 42.2	1320	170.0	67.14	I. S. O.
Y 4	NKG	Maze	35 53 28.1	137 09 19.0	590	155.7	81.00	T. S. O.
Y 5	SZW	Shiozawa	36 03 06.6	137 29 20.7	1190	178.1	91.68	T. S. O.
Y 6	ONG	Ohnogawa	36 08 00.9	137 40 20.0	1150	-172.4	101.59	T. S. O.
Y 7	KYM	Kiyomi	36 07 55.5	137 10 59.6	690	163.0	105.14	T. S. O.
Y 8	TGK	Tagoroke	36 15 05.2	137 29 44.3	930	178.7	113.80	T. S. O.
Y 9	KTJ	Kamitakara	36 16 48.8	137 19 37.8	800	171.4	118.30	K. C. M. O.
Y 10	NHJ	Nirehara	36 30 48.5	137 14 18.0	220	169.8	145.15	K. C. M. O.
the Tohkai district								
O 1	TYN	Toyone	35 07 58.5	137 40 10.4	650	-52.2	16.84	F. Yamazaki
O 2	SKM	Sakuma	35 08 11.3	137 49 19.3	320	-69.9	28.94	R. Shichi, M. Ukawa
O 3	KDK	Kadoketa	35 05 54.9	137 55 26.7	460	-68.8	39.13	H. Fukui, T. Okuda
O 4	ORK	Orokubo	35 06 35.6	138 02 54.6	1070	-74.9	49.53	M. Yamada, I. Watanabe

O 5	MAE	Maeyama	34°55′15.0″	138°03′46.0″	490m	S -55.5°W	59.70km	Tokai Univ.
O 6	MNY	Mineyama	35 03 09.0	138 12 17.3	580	-72.8	65.00	T. Ooida
O 7	MZI	Mizumiiro	35 02 38.5	138 17 37.0	400	-74.0	73.02	A. Yamamoto
O 8	TOK	Tohkoji	34 51 27.5	138 11 49.7	100	-56.4	73.80	Tokai Univ.
O 9	FUJ	Fujigawa	35 13 54.0	138 28 19.0	125	-90.4	86.33	F. C. M. O.
O 10	TOI	Toi	34 53 40.5	138 48 25.3	100	-72.6	122.71	O. Kato
O 11	IYM	Ichiyama	34 54 11.9	138 55 59.9	210	-74.4	133.47	E. R. I.
O 12	JIZ	Jizodo	34 54 46.0	138 59 53.0	300	-75.5	138.89	N. R. C. D. P.
O 13	SRT	Shirata	34 48 48.8	139 00 44.4	255	-71.4	143.36	M. Furumoto, K. Izuhara
O 14	KWZ	Kawazu	34 45 45.0	138 59 24.0	65	-69.0	143.40	E. R. I.
O 15	OKN	Okuno	34 55 54.8	139 04 14.5	140	-77.0	144.81	E. R. I.
O 16	NRM	Naramoto	34 49 35.8	139 03 52.2	200	-72.5	147.42	E. R. I.
the others								
1	TYH	Toyohashi	34 45 49.2	137 28 07.8	70	5.6	51.52	M. C. M. O.
2	KSO	Kashio	35 34 46.8	138 02 55.5	805	-129.4	61.77	I. S. O.
3	MAT	Matsushiro	36 32 31.0	138 12 25.0	407	-157.1	158.51	J. M. A.

* H. M. O.; Hokuriku Microearthquake Observatory, Kyoto University, A. S. O.; Abuyama Seismological Observatory, Kyoto University, K. C. M. O.; Kamitakara Crustal Movement Observatory, Kyoto University, T. M. O.; Tottori Microearthquake Observatory, Kyoto University, I. S. O.; Inuyama Seismological Observatory, Nagoya University, T. S. O.; Takayama Seismological Observatory, Nagoya University, M. C. M. O.; Mikawa Crustal Movement Observatory, Nagoya University, F. C. M. O.; Fujigawa Crustal Movement Observatory, Tokyo University, E. R. I.; Earthquake Research Institute, Tokyo University, N. R. C. D. P.; National Research Center for Disaster Prevention, and J. M. A., Japan Meteorological Agency.

** (T); seismograms telemetered to H. M. O. and (D); seismograms on the drum reorder.

Table 2. Travel times.

Station No.	Code	Δ	T	Class*	T-O	T-O-Δ/6	Later phases
the Kinki district			09h00m				09h00m
K1	TAR	93.68km	20.34s	A	16.15s	0.54s	
K2	UGK	96.77	20.90	A	16.71	0.58	
K3	OCH	106.53	22.30	A	18.11	0.35	
K4	AZJ	112.53	23.27	A	19.08	0.32	23.71s
K5	KMY	114.22	23.65	A	19.46	0.42	
K6	KJY	120.49	24.65	A	20.46	0.38	
K7	OHM	131.25	26.44	A	22.25	0.38	26.74
K8	ORJ	131.58	26.53	A	22.34	0.41	26.77
K9	MHJ	144.34	28.66	A	24.47	0.41	
K10	MHD	144.78	28.77	A	24.58	0.45	
K11	BHO	150.25	29.60	A	25.41	0.37	
K12	UJI	159.83	31.29	C	27.10	0.46	
K13	KGM	161.22	31.16	A	26.97	0.10	
K14	KHK	169.55	32.46	A	28.27	0.01	32.90
K15	YGI	184.12	34.51	A	30.32	-0.35	35.29
K16	TNJ	211.56					39.74
K17	HMT	225.74	40.52	C	36.33	-1.29	41.98
the Mino district							
M1	YHG	9.34	05.96	A	1.77	0.21	
M2	OOK	20.96	08.04	A	3.85	0.36	
M3	INU	47.06	12.46	A	8.27	0.43	
M4	UNM	57.46	14.26	A	10.07	0.49	
M5	SPJ	71.05	16.58	B	12.39	0.55	
M6	MDR	92.61	20.02	A	15.83	0.40	
M7	OOI	95.84	20.48	B	16.29	0.32	
M9	UMS	103.86	21.82	A	17.63	0.32	
M10	TKY	107.56	22.49	A	18.30	0.37	
M11	YMT	110.83	23.02	B	18.83	0.36	
M13	IMJ	127.63	25.75	A	21.56	0.29	
M14	KAJ	128.28	26.06	B	21.87	0.49	
M15	HKJ	142.64	28.54	C	24.35	0.58	
M16	KMJ	156.26	30.77	A	26.58	0.54	
M17	FKJ	159.21	30.92	B	26.73	0.20	
the eastern Gifu district							
Y1	KSM	55.39	14.00	A	9.81	0.58	
Y2	MKD	66.58	15.73	B	11.54	0.44	
Y3	MID	67.14	15.89	B	11.70	0.51	
Y4	NKG	81.00	18.35	B	14.16	0.66	
Y5	SZW	91.68	19.96	C	15.77	0.49	
Y6	ONG	101.59	21.75	B	17.56	0.63	
Y7	KYM	105.14	22.24	B	18.05	0.53	
Y8	YGK	113.80	23.78	B	19.59	0.62	

Station No.	Code	Δ	T	Class*	T-O	T-O-Δ/6	Later phases
Y 9	KTJ	118.30km	24.29s	A	20.10s	0.38s	
Y 10	NHJ	145.15	28.73	C	24.54	0.35	
the Tohkai district							
O 1	TYN	16.84	7.35	A	3.16	0.35	
O 2	SKM	28.94	9.38	A	5.19	0.37	
O 3	KDK	39.13	11.08	A	6.89	0.37	
O 4	ORK	49.53	13.12	A	8.93	0.68	
O 5	MAE	59.70	14.96	A	10.77	0.82	
O 6	MNY	65.00	15.93	A	11.74	0.91	
O 7	MZI	73.02	17.17	A	12.98	0.81	
O 8	TOK	73.80	17.58	A	13.39	1.09	
O 9	FUJ	86.33	19.4	B	15.2	0.8	
O 10	TOI	122.71	25.12	A	20.91	0.46	25.36
O 11	IYM	133.47	26.83	C	22.58	0.34	26.90
O 12	JIZ	138.89	27.76	B	23.57	0.42	27.84
O 13	SRT	143.36	28.27	A	24.08	0.19	28.44, 28.61
O 14	KWZ	143.40	28.3	C	24.1	0.2	
O 15	OKN	144.81	31.1	C	26.9	2.8	
O 16	NRM	147.42	29.1	C	24.9	0.3	
the others							
	TYH	51.52	13.33	B	9.14	0.55	
	KSO	61.77	14.88	B	10.69	0.40	
	MAT	158.51	31.6	C	27.4	1.0	

Shot time : September 2, 1976, 09 h 00 m 04.193 sec.

* A, B and C denote that the accuracies of the onset time are within 0.05 sec, 0.1 sec and over 0.1 sec, respectively.

2. Crustal structures in the Kinki and Mino districts (the western profiles)

2.1 Observed results

Reduced travel times in the western profiles are plotted in Figs. 2 and 3. Figs. 4, 5 and 6 show the seismic record sections in the western profiles. Fig. 7 shows the stations in the Kinki district and the shot points of the past explosion experiments in these districts.

The travel times of each wave group are represented as the following formulae. The southern section traversing Lake Biwa (Biwako) is shown by the line I-K in Fig. 1 and the northern section traversing southern Gifu Prefecture and Fukui Prefecture is shown by the line I-M in Fig. 1.

1. the southern section

P_1; $T_1=\Delta/5.3$ $\quad$ ($\Delta<15$ km)

P_2; $T_2=\Delta/5.87+0.27$ $\quad$ (15 km$<\Delta<$80 km)

P_3; $T_3=\Delta/5.92+0.10$ (100 km$<\Delta<$150 km)
P_4; $T_4=\Delta/6.81+3.30$ (150 km$<\Delta$)
P_5; $T_5=\Delta/6.19+1.33$ (100 km$<\Delta$)

2. the northern section

P_1; $T_1=\Delta/5.3$ ($\Delta<$15 km)
P_2; $T_2=\Delta/5.87+0.27$ (15 km$<\Delta<$60 km)
P_3; $T_3=\Delta/6.10+0.68$ (60 km$<\Delta$)
P_5; $T_5=\Delta/6.20+1.33$ (70 km$<\Delta$)

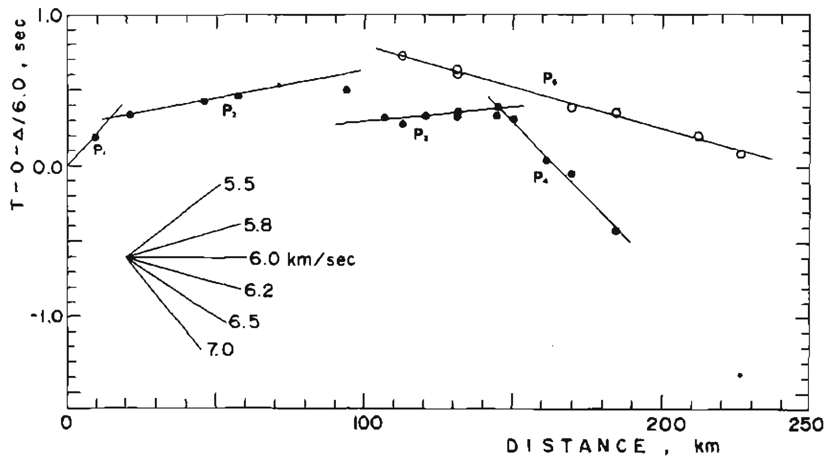

Fig. 2. Reduced travel times in the Kinki district. ●, ○ and · denote that the accuracies of the onset time are within 0.05 sec, 0.1 sec and over 0.1 sec, respectively.

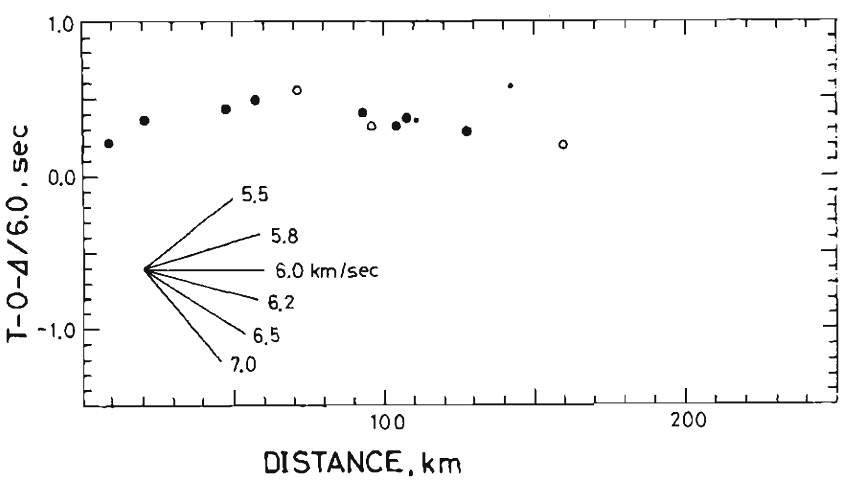

Fig. 3. Reduced travel times in the Mino district. Symbols are the same to those in Fig. 2.

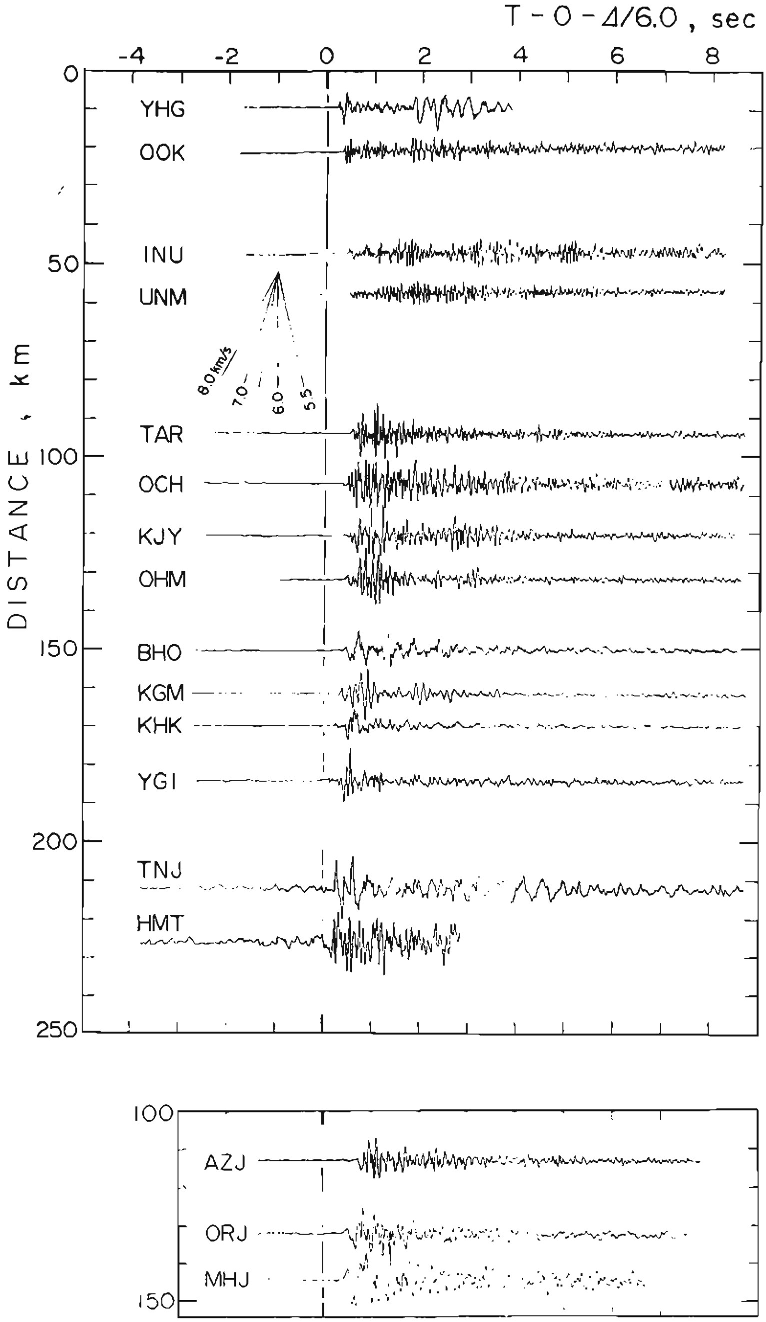

Fig. 4. Seismic record sections in the Kinki district. Lower three seismograms were obtained at the stations along the north coast of Lake Biwa.

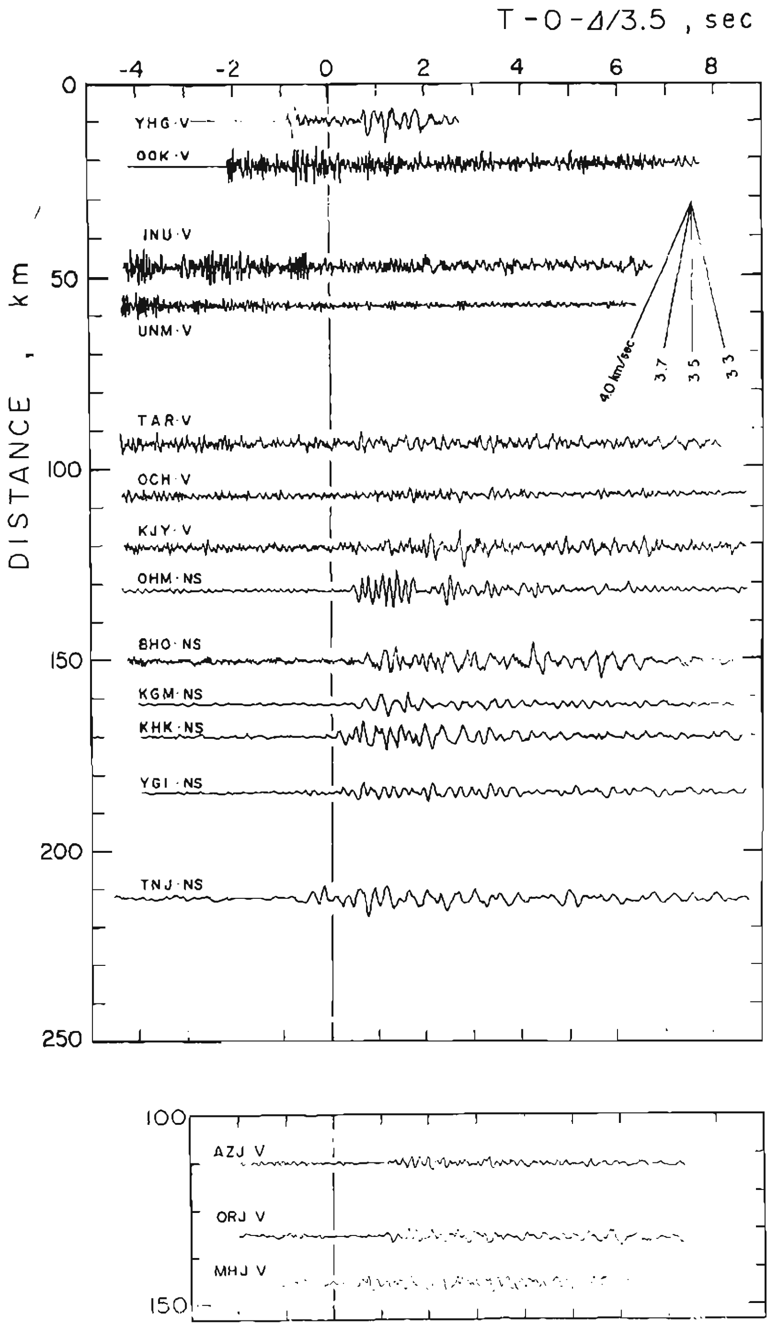

Fig. 5. Seismic record sections for the shear waves in the Kinki district. V and NS denote the vertical and NS component respectively.

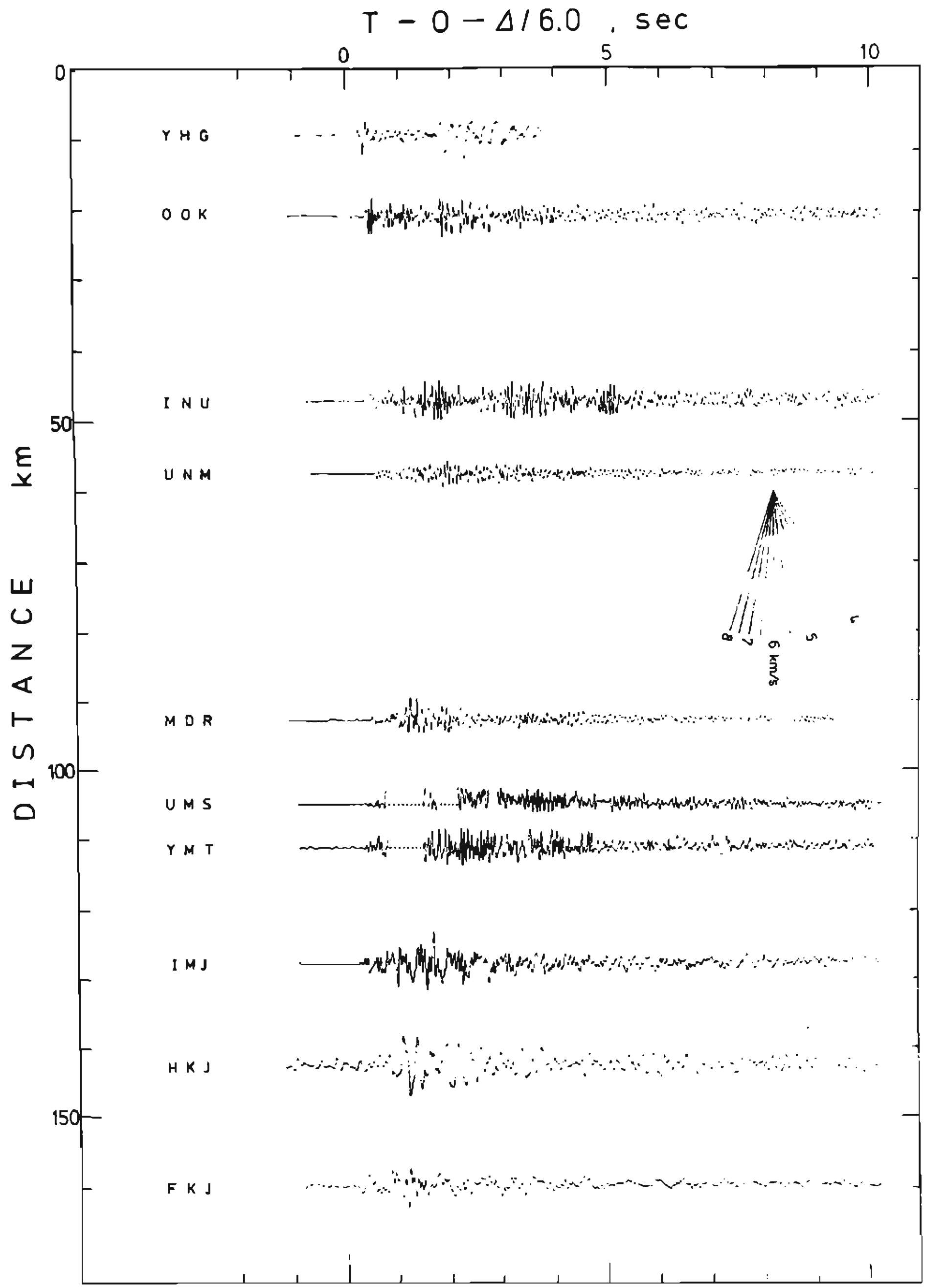

Fig. 6. Seismic record sections in the Mino district. Seismograms at HKJ was recorded by the EW component seismometer.

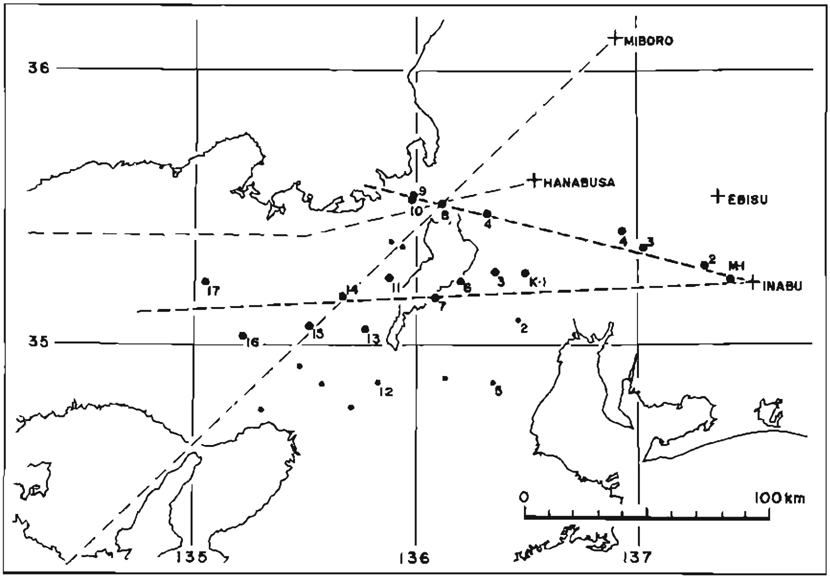

Fig. 7. Observation stations in the Kinki district and the shot points of the Inabu and the past explosions.
●; stations used in this analysis, ・; stations not used, +; shot points.

The characteristic features of the observed results are as follows:

(1) In the travel time curves shown in Fig. 2 of the southern profile, there is a gap, about 0.3 sec, at the shot distance of about 100 km. The travel time at K1 (TAR) indicates the intermediate value between the values indicated by P_2 and P_3 travel time curves.

(2) The later phase P_5 was well observed with large amplitude in the southern section.

(3) Good records of shear waves were obtained by the horizontal component seismometers in the networks of Abuyama Seismological Observatory and Hokuriku Microearthquake Observatory.

(4) Pn waves were not obtained.

2.2 The velocity in the surface layer

P_1 wave was obtained at only one station M1, so that the small quarry blasts near Tajimi, about 6 km southeast of Inuyama Seismological Observatory (INU), were used to determine the velocity in the surface layer. Observations were carried out by one of the authors (I. Yamada), and the seismic record sections and travel time differences from INU to other stations are shown in Fig. 8 and Table 3, respectively.

Though seismograms at each station were due to different quarry blasts, two shot times of all the quarry blasts observed were recorded at the shot sites and seismic waves generated by these blasts were observed at INU. The travel time difference between these two quarry blasts was within 0.01 sec at INU. Then we calculated travel time to each station by virtue of the travel time difference from that to INU.

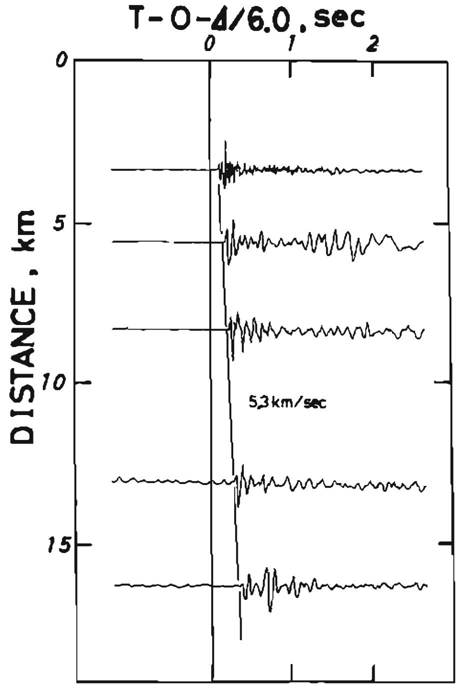

Fig. 8. Seismic record sections obtained by the near Tajimi quarry blasts.

Table 3. Location of observation stations for the near Tajimi quarry blasts, distances and travel time differences from INU.

Code	Observation point	Latitude (N)	Longitude (E)	Height	Δ	$T_{obs}-T_{INU}$
NSO	Nishio	35°19′15.0″	137° 2′58.0″	150m	3.7km	-0.46sec
INU	Inuyama	35 20 58.8	137 1 42.8	132	5.9	0.0
IMI	Imai	35 21 36.5	137 0 3.9	100	8.7	0.58
TGO	Tsugao	35 23 34.4	136 57 49.9	85	7.4	1.39
UNM	Unuma	35 24 45.4	136 56 2.3	120	10.7	2.02

From these observations, we can estimate the velocity in the surface layer. The velocity thus determined is 5.3 km/sec. This value is adopted as the velocity in the first layer in the Kinki and the Mino districts.

2.3 Assumptions

There is no reverse profile, so the analyses of the travel times are carried out under the following assumptions:

(1) The velocity in the surface layer is 5.3 km/sec obtained in the above experiments.

(2) The velocity in the 2nd layer (so-called the granitic layer) is 6.0 km/sec.

Aoki et al.[2] determined that the velocity in this granitic layer would be 6.0 km/sec from the Ebisu explosion experiment, August 26, 1967, about 40 km northwest from Inabu.

(3) The 3rd layer and 4th layer are horizontal.

(4) In the southern section the dip-slip fault exists at a distance of 88 km from Inabu, but does not reach the 3rd layer. The travel time of P_3 waves is about 0.3 sec faster than that of P_2 waves at the shot distance of 100 km, and the apparent velocity increases by 1% from 5.87 km/sec to 5.92 km/sec.

(5) There is no fault in the northern section.

2.4 Crustal structures

(1) The southern section

The crustal structure in the southern section is determined on the basis of the above assumptions. The 2nd layer is determined so that the travel time of K1 fits the travel time of refracted waves at the fault plane and P_3 waves fit the travel times of waves passed through the lower end of the fault. Making a comparison between

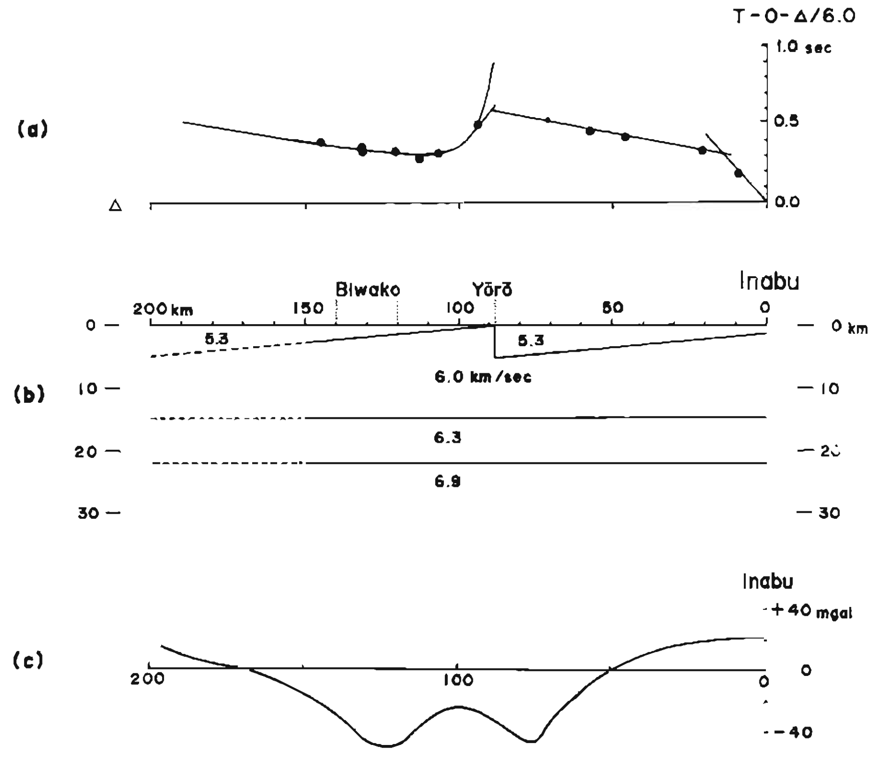

Fig. 9. (a) Theoretical travel time curves calculated from the structure shown in (b) and the observed travel times. (b) The crustal structure in the Kinki district along the line I-K shown in Fig. 1. (c) Terrain corrected Bouguer anomaly along the line I-K.

the velocity, 6. 0 km/sec, and the apparent velocities, 5. 87 km/sec and 5. 92 km/sec, the upper boundary of the 2nd layer may be considered to descend westwards with a dip of 2. 5° from Inabu to Yoro and from Yoro to Lake Biwa. Depths of this boundary are 1. 5 km at Inabu, 5. 4 km and 0. 1 km at the east and west sides of the Yoro Fault respectively, and 2. 8 km at the shot distance of 150 km. The vertical dislocation of the Yoro Fault is 5. 3 km. In the geological view point, Kuwahara[5] said that the Yoro Fault with the strike of NNW crosses this southern section, the west side of this fault was lifted up about a few kilometers and the Nobi Plain was tilting in the direction perpendicular to the Yoro Fault with a dip of about 3°.

If the velocity in the 2nd layer is assumed to be 5. 9 km/sec instead of 6. 0 km/sec, the gap of the travel times show the negative thickness of the surface layer. Then the assumption of 6. 0 km/sec would be better than 5. 9 km/sec. The fault is assumed here to be vertical, but the travel time will be satisfied by a little change of location of the fault, even if the fault be slightly inclined.

The velocity in the 3rd layer is so determined that the apparent velocity of P_5 wave, with large amplitude, refracted from the 3rd layer becomes 6. 19 km/sec. The velocity is 6. 3 km/sec and the depth from the surface to the 3rd layer is 14. 8 km. The 4th layer is determined in the same way. The velocity is 6. 9 km/sec, and it is 22. 1 km in depth.

Fig. 9 (b) is a derived crustal structure in the southern section, but the Moho discontinuity is not determined in this analysis. Theoretical travel time curves of refracted waves from the lst and 2nd layers are shown in Fig. 9 (a), and the Bouguer anomaly obtained from maps by Hagiwara[6] is shown in Fig. 9 (c).

(2) The northern section

The crustal structure along this section is determined under the assumptions that the velocities in the lst and 2nd layers are 5. 3 km/sec and 6. 0 km/sec, respectively. Two branches of P_2 and P_3 waves suggest a downwarping of the layer. The interface between the lst and 2nd layers is estimated to descend northwestwards with a dip of

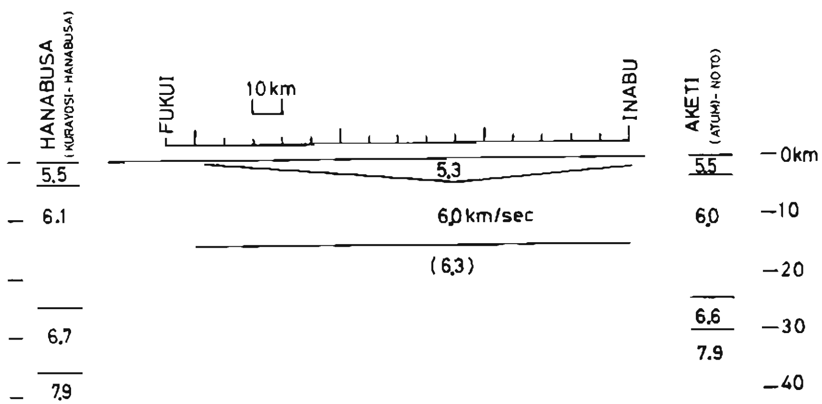

Fig. 10. The crustal structure in the Mino district along the line I-M shown in Fig. 1.

2.5° through the apparent velocity of P_2 waves. The intercept time of P_2 indicates the boundary depth of 1.5 km at Inabu. The apparent velocity of P_3 waves indicates that the above interface changes its inclination and begins to ascend northwestwards with a dip of 1.7°. The shot distance of the deepest point is about 60 km and the depth at this point is 4.1 km. These are computed from the intercept time of P_3 and the assumptions of the velocities in two layers. The depth of interface between the 2nd and 3rd layers was determined assuming that the velocity in the 3rd layer was 6.3 km/sec discussed in the last section. Taking into consideration the above results, we can estimate the crustal structure in this section as shown in Fig. 10.

2.5 Discussion

In 1964, the first Hanabusa explosion was detonated at the point shown in Fig. 7, about 100 km northwest of Inabu, as a reverse profile of the Kurayosi explosion (R. G. E. S.[7]). Travel times of the first arrivals and clear later phases are plotted in Fig. 11. From P_1' and P_2' drawn on the reduced travel time curves of the first Hanabusa explosion, we obtained the following formulae:

$$P_1';\ T_1 = \Delta/5.3$$
$$P_2';\ T_2 = \Delta/5.85 + 0.30$$

The apparent velocities of 5.3 km/sec and 5.85 km/sec in the first Hanabusa explosion experiment are nearly the same as in our results. The thickness of the surface layer is 1.7 km, which is 1.1 km thicker than our result at the west of Lake Biwa. This difference, however, is not so significant, because the larger the value of the velocity in the 2nd layer is, the thicker is the 1st layer at these areas. Clear later phase is also found with the apparent velocity of 6.3 km/sec corresponding to P_3 phase. We can derive the structure ascending westwards with the same velocity,

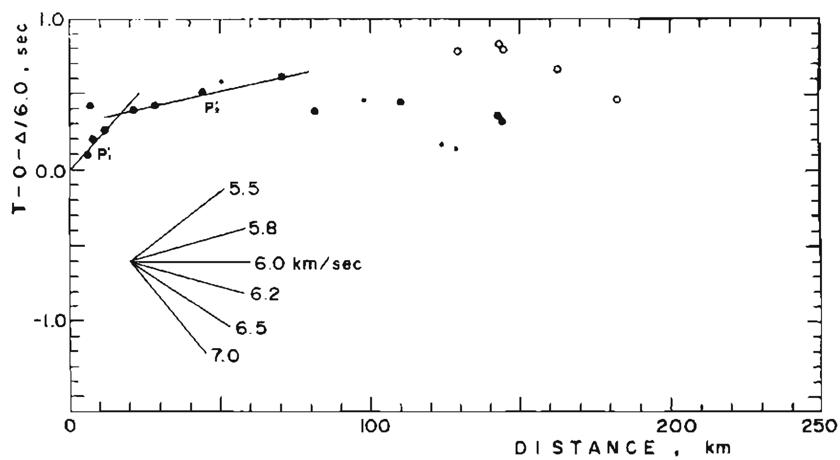

Fig. 11. Reduced travel times in the Hanabusa explosion experiment (compiled from R. G. E. S.[7]). ●; very clear first arrivals, ·; good first arrivals and ○; good later phases.

6.7 km/sec, like Model I by Sasaki et al.[1].

Since 1957, several explosions had been made at Miboro (R. G. E. S.[8]). The travel times of refracted waves from the 2nd layer were represented as the following formulae for model I in the western profile B (Mikumo et al.[9]) :

$$P_{21};\ T_{21}=\Delta/5.81+0.31 \quad (28\ \mathrm{km}<\Delta<112\ \mathrm{km})$$
$$P_{22};\ T_{22}=\Delta/6.16+1.40 \quad (112\ \mathrm{km}<\Delta<168\ \mathrm{km})$$

These travel times correspond well to our P_2 (or P_3) and P_5 waves in the southern section.

In Miboro explosions, the travel time curves of P_{21} and P_{22} waves were not overlapped and the downwarping structure was derived. But in our profile, both P_3 and P_5 are obtained at stations of the shot distance from 100 km to 150 km, so it is plausible that there is the layer with the velocity of 6.3 km/sec as well as the layer with that of 6.0 km/sec.

The Bouguer anomaly, along the southern section, shown in Fig. 9 (c) increases rapidly about 20 mgal from the shot distance of 75 km to that of 100 km. This corresponds to the existence of the Yoro Fault with a few kilometers upheaval in the southwestern part. And the decrease of the Bouguer anomaly from Inabu to Yoro agrees well with the westward descending of the layer with the velocity of 6.0 km/sec.

Clear shear waves are recorded at many stations in the horizontal components, especially at K7 (OHM) and K14 (KHK) as seen in Fig. 5. These travel times are 37.94 sec and 48.33 sec respectively and the value of Vp/Vs is 1.71.

The later phase of which the apparent velocity is 6.2 km/sec has large amplitude in comparison with the initial phase. So there may be a velocity gradient in the granitic layer.

3. Crustal structure in the Tohkai district
(the eastern profile)

3.1 Observed results

The temporal stations were installed along the line I-O in Fig. 1 and seismic record sections are shown in Fig. 12. The reduced travel times are plotted in Fig. 13. From these figures, we can find the travel time gap about 0.5 sec at a distance of about 50 km from the shot point. The centers of 'T' and 'K' in Fig. 13 mean the reduced travel times at Mikawa Crustal Movement Observatory in Toyohashi, 20 km south of the Median Tectonic Line, and at Kashio near Iida, just on the Median Tectonic Line, respectively, though these two stations are not on the line I-O in Fig. 1.

Clear later phases can be found in Fig. 12 and are used in this analysis. Shear waves are also found in this area and the seismic record sections of these shear waves are shown in Fig. 14 with a reduced velocity of 3.5 km/sec. There is also the travel time gap at the shot distance of about 50 km. Solid lines in Fig. 13 are

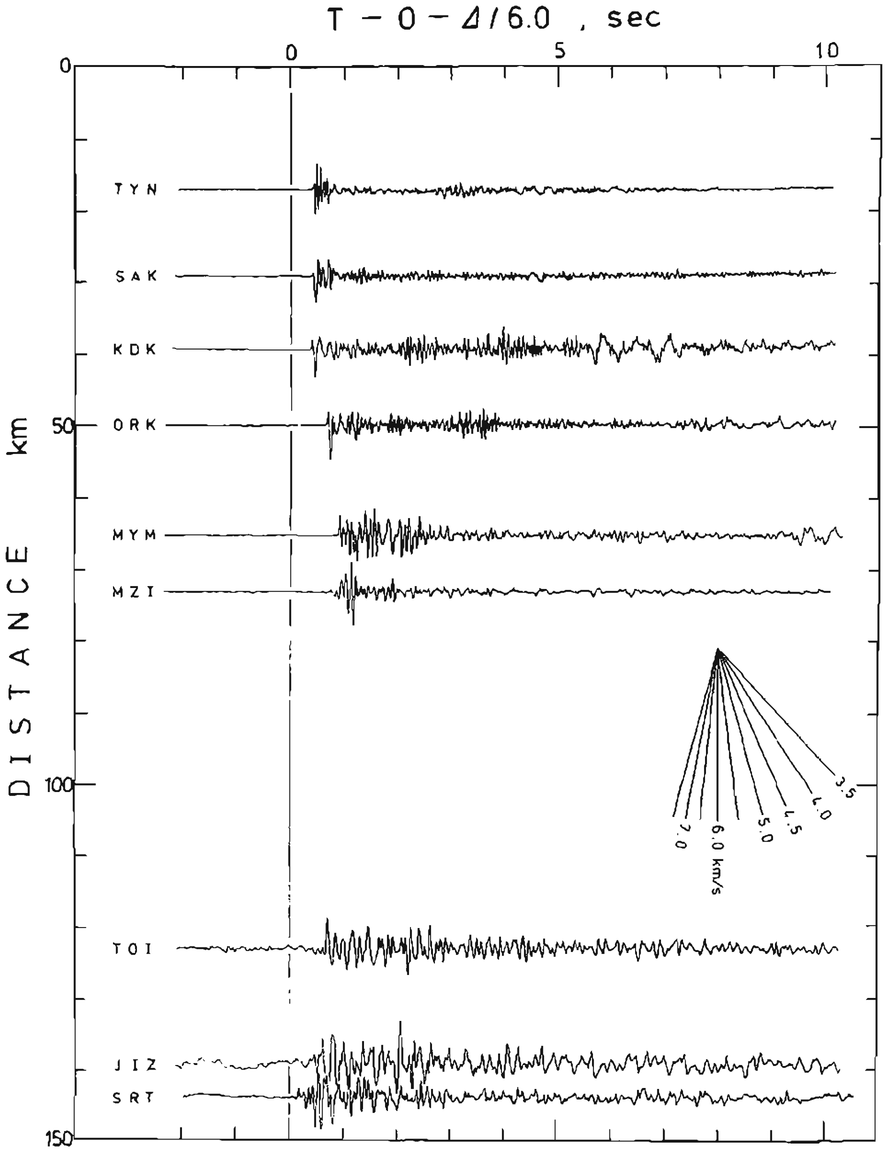

Fig. 12. Seismic record sections in the Tohkai district.

the travel time curves calculated from the model shown in Fig. 15.

3.2 Amplitude

From the result of the Oshima explosion experiment, Ikami[10] pointed out that the velocity amplitude decay is represented as Δ^{-3} in the frequency range from 5 Hz to 10 Hz, where Δ is the epicentral distance. In this Inabu explosion experiment, the relation between the velocity amplitude and the shot distance is also shown in

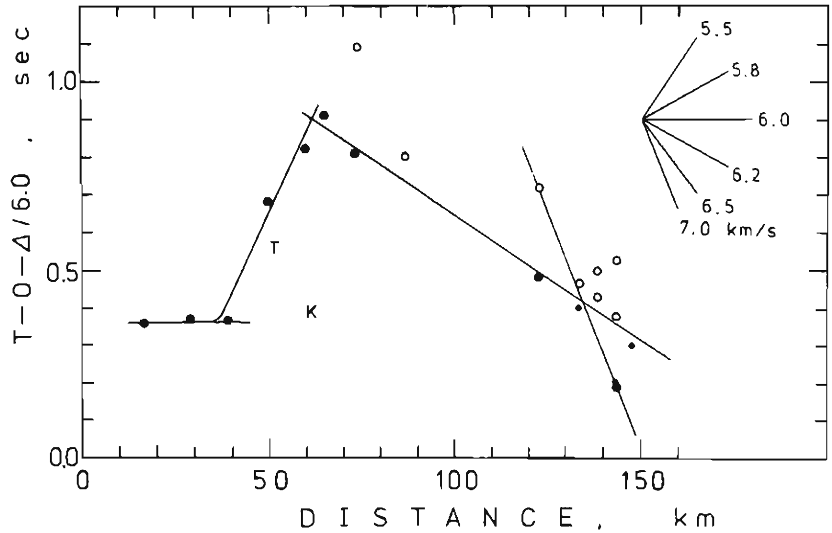

Fig. 13. Reduced travel times in the Tohkai district. Symbols are the same to those in Fig. 2.

Fig. 16. In this figure, amplitude decay is represented as Δ^{-2} in the frequency range from 5 Hz to 20 Hz and we can confirm that the attenuation factor in this area is normal, and that the large attenuation factor in the Izu Peninsula is due to the volcanic origin.

3.3 Crustal structure

The Oshima explosions are not truly the reverse profiles of the Inabu quarry blast, so the crustal structure in the Tohkai district is determined assuming the results by Ichikawa and Yoshida[11] and Aoki et al[2].

The velocity in the first layer in the western part of this profile is assumed to be 5.5 km/sec. In section 2, the value of 5.3 km/sec was adopted as the velocity in the surface layer from the data obtained by the small quarry blast observations. But the velocity in the first layer in this area has not been found, so the velocity of 5.5 km/sec by Aoki et al.[2] is adopted. To find the velocity in this layer is the problem to be determined from now on. In the Kawazu explosion experiment, Hotta et al.[12] determined the velocity in the first layer as 2.84 km/sec. On the other hand, Ichikawa and Yoshida[11] determined from the explosion experiments in Sagami Bay that the velocity of the first layer was 4.7 km/sec. Though we question these two models, the velocity of the first layer of the Izu Peninsula is assumed to be 4.7 km/sec. The velocity in the second layer of this area is assumed to be 6.0 km/sec as ordinary velocity in the granitic layer. Though the layer with the velocity of 6.3 km/sec in the Kinki and Mino districts was found, we could not find the phase due to this layer. The velocity of the basaltic layer is assumed to be 6.8-6.9 km/sec.

Following observation results would be explained by the vertical offset at the Median Tectonic Line; (1) there is a travel time gap at the shot distance of about

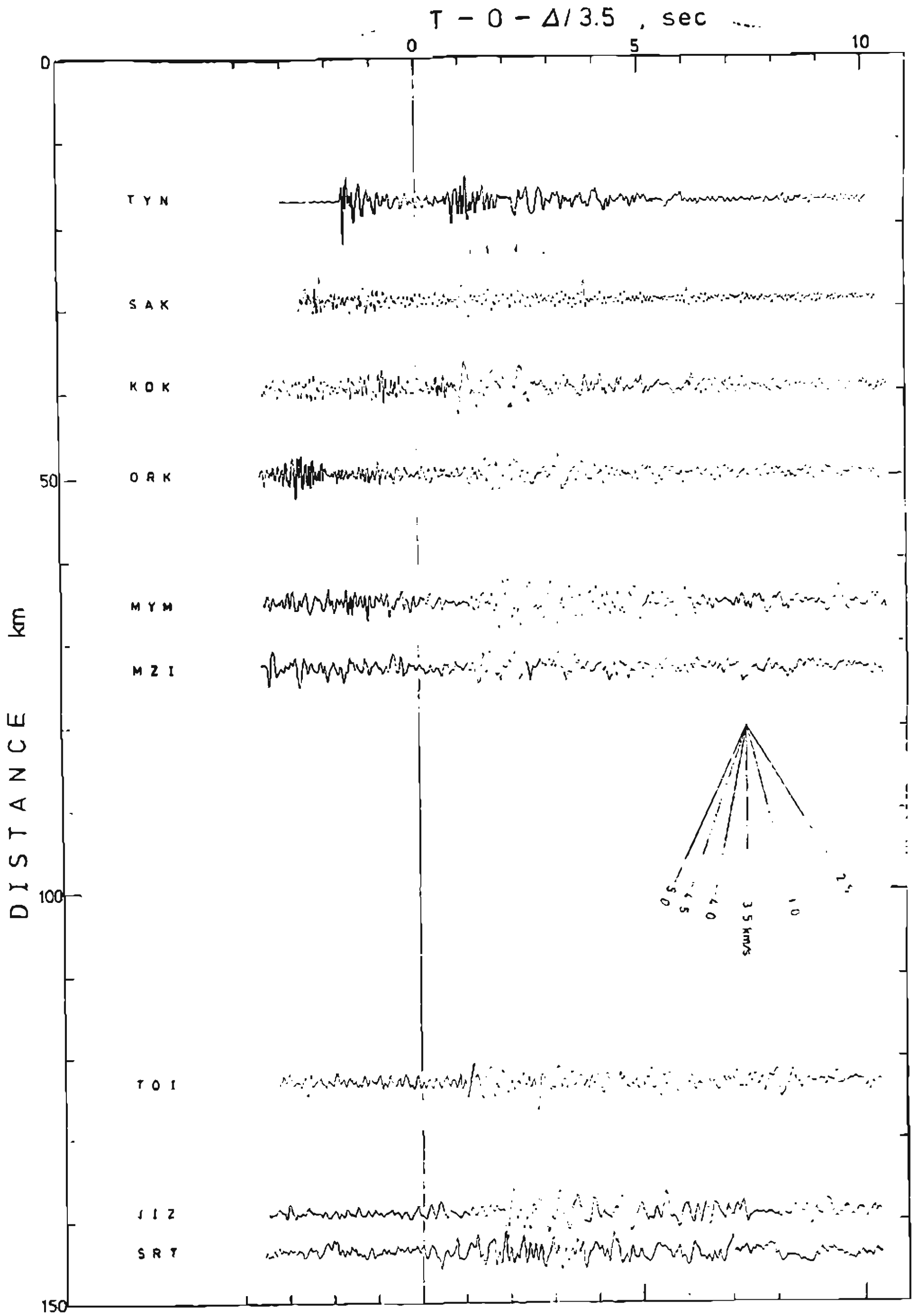

Fig. 14. Seismic record sections for the shear waves in the Tohkai district.

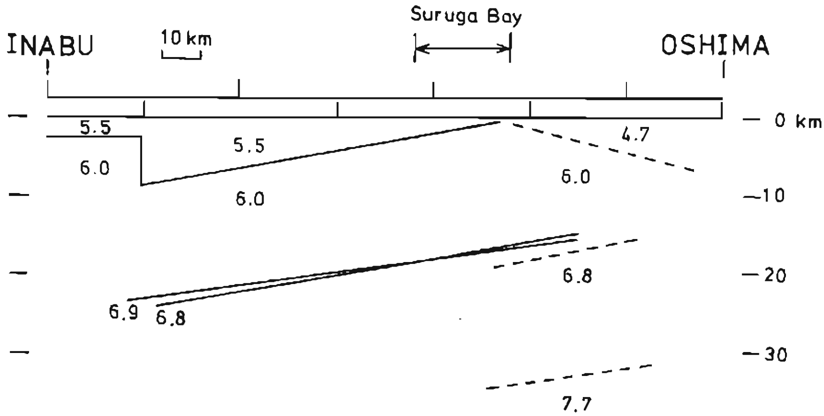

Fig. 15. The crustal structure in the Tohkai district along the line I-O shown in Fig. 1.

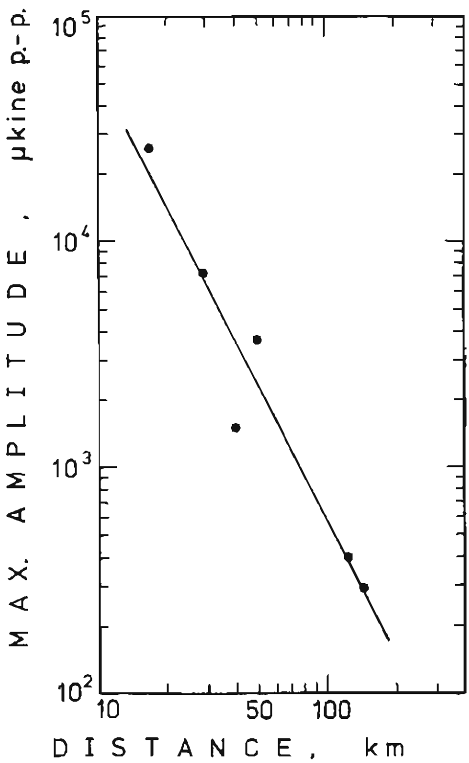

Fig. 16. Relation between the velocity amplitude and the shot distance. Amplitude was measured from peak to peak.

50 km, (2) the reduced travel time at Toyohashi is nearly same as that at O4, 25 km east of the Median Tectonic Line and (3) the reduced travel time at Iida is the same as those at O1, O2 and O3. From these travel times, we might estimate that the west side was lifted up about 6.3 km. This amount of offset is reasonable from the geological view point (M. Adachi, 1977, personal communication). This area coincides with the area of thick Shimanto belt.

In the eastern part of the Shimanto belt, there exists the Itoigawa-Shizuoka Tectonic Line, which is also thought to be the large tectonic line. But there were no stations in Suruga Bay nor on the coast of it, we could not find the effect due to this tectonic line in the travel time curve and then, in this paper, we do not take into consideration this tectonic line. On these assumptions, we constructed the crustal structure along the line I-O in Fig. 1 and showed it in Fig. 15.

The thickness of the first layer in the Shimanto belt is 8.8 km at the east of the Median Tectonic Line and is 2.6 km at the western end of Suruga Bay. The depth of the first layer at the west coast of the Izu Peninsula is very shallow and may be less than 1 km. In Fig. 13, we can draw the several travel time curves of the later phases and one of which may indicate the reflected waves from the boundary of the granitic and basaltic layers. The depth of this boundary was determined by the model which could explain the travel time curve most thoroughly. The boundary thus obtained is ascending eastwards with the angle of 4° (assuming the velocity of 6.9 km/sec) or 7° (assuming the velocity of 6.8 km/sec). The crustal structure determined by Ikami[13] is also shown in Fig. 15 by the dotted lines and we can see the conformability of the boundary depths. Then we may conclude that the depth of the boundary of the basaltic and granitic layers will differ little from the true one.

3.4 Discussion

Ikami[10),13] pointed out from the results of the Oshima explosion experiments that the travel time delay at the stations to the west of the Suruga Bay are as large as 1.0 sec to 1.5 sec compared to those estimated from the travel times in the Izu Peninsula. These travel time delays were also pointed out by the Research Group for Aftershocks[14] and Utsu[15]. It was important to decide whether this travel time delay was due to the crustal structure or the velocity reduction before a large earthquake. So the profile from Inabu to Oshima was selected to investigate this time delay.

As shown in Fig. 14, we can see the shear waves. The value of Vp/Vs, calculated using these phases is 1.71, the same as the value obtained in the Kinki district.

From the results in this study, it may be concluded that the time delay found in the Tohkai district is due to the thick Shimanto group and complicated crustal structure around Suruga Bay.

4. Conclusion

We can see the two apparent velocities of 5.8-5.9 km/sec and 6.2-6.3 km/sec in the reduced travel time curves in Figs. 2 and 3. These two apparent velocities can also be seen in the reduced travel time curves of the Hanabusa and the Miboro explosions. From these results, it would be concluded that the granitic layer might be divided into two layers of the velocities of 6.0 km/sec and 6.3 km/sec and there might be a velocity gradient in the granitic layer. But two layers in the granitic layer could not be verified in the eastern profile.

Another fact to which we would like to give emphasis is the travel time gap shown in Figs. 2 and 13. The former is due to the Yoro Fault and the gap of the travel time is explained by the fault with a vertical offset of 5.3 km. The latter is due to the Median Tetonic Line and is explained with a vertical offset of 6.3 km.

Acknowledgements

We thank the members of seismological observatories of universities, the National Research Center for Disaster Prevention and Japan Meteorological Agency who placed their data at our disposal. We would also like to thank the members of Nagoya University, Kyoto University, Gifu University, Aichi Institute of Technology, Tokai University and Aichi University of Education for their cooperation in the observation program and for their discussion and advice.

Our hearty thanks are due to Hanabishi-Kenzai Co., Ltd. for giving us the opportunity for this experiment. Financial Aid was partly granted by Kagami Memorial Foundation of Tokyo Marine and Fire Insurance Company and partly by Grant in Aid for Scientific Research, the Ministry of Education of Japan.

References

1) Sasaki, Y., S. Asano, I. Muramatu, M. Hashizume and T. Asada: Crustal Structure in the Western Part of Japan Derived from the Observation of the First and Second Kurayosi and the Hanabusa Explosions (Continued). Part 2. Crustal Structure in the Western Part of Japan (Continued), Bull. Earthq. Res. Inst., Vol. 48, 1970, pp. 1129-1136.
2) Aoki, H., T. Tada, Y. Sasaki, T. Ooida, I. Muramatu, H. Shimamura and I. Furuya: Crustal Structure in the Profile across Central Japan as Derived from Explosion Seismic Observations, J. Phys. Earth, Vol. 20, 1972, pp. 197-223.
3) Yoshii, T., Y. Sasaki, T. Tada, H. Okada, S. Asano, I. Muramatu, M. Hashizume and T. Moriya: The Third Kurayosi Explosion and the Crustal Structure in the Western Part of Japan, J. Phys. Earth, Vol. 22, 1974, pp. 109-121.
4) Aoki, H. and I. Muramatu: Crustal Structure in the Profile across Kinki and Shikoku, Japan, as Derived from the Miboro and the Toyama Explosions, Zisin, Ser. II, Vol. 27, 1974, pp. 104-109 (in Japanese with English abstract).
5) Kuwahara, T.: The Noobi Basin and its Fault Block Movements, Quaternary Res., Vol. 7, 1968, pp. 235-247. (in Japanese with English abstract).
6) Hagiwara, Y.: Analyses of Gravity Values in Japan, Bull. Earthq. Res. Inst., Vol. 45, 1967, pp. 1091-1228.
7) R. G. E. S.: Crustal Structure in the Western Part of Japan Derived from the Observation of the First and Second Kurayosi and the Hanabusa Explosions. Part 1. Observation of Seismic Waves Generated by the First and Second Kurayosi and the Hanabusa Explosions, Bull. Earthq. Res. Inst., Vol. 44, 1966, pp. 89-107.

8) R. G. E. S.: Crustal Structure in Central Japan as Derived from the Miboro Explosion-Seismic Observations. Part 1. Explosions and Seismic Observations, Bull. Earthq. Res. Inst. Vol. 39, 1961, pp. 285-326.

9) Mikumo, T., M. Ôtsuka, T. Utsu, T. Terashima and A. Okada: Crustal Structure in Central Japan as Derived from the Miboro Explosion-Seismic Observations. Part 2. On the Crustal Structure, Bull. Earthq. Res. Inst., Vol. 39, 1961, pp. 327-349.

10) Ikami, A.: Attenuation of the Seismic Waves beneath the Izu Peninsula, Zisin, Ser. II, Vol. 29, 1976, pp. 15-24 (in Japanese with English Abstract).

11) Ichikawa, K. and M. Yoshida: Deep drilling plan in UMP, Chishitsu Nyusu, Vol. 171, 1968, pp. 1-9 (in Japanese).

12) Hotta, H., S. Murauchi, T. Usami, E. Shima, Y. Motoya and T. Asanuma: Crustal Structure in Central Japan along Longitudinal Line 139°E as derived from Explosion-Seismic Observations, Bull. Earthq. Res. Inst., Vol. 42, 1964, pp. 533-541.

13) Ikami, A.: Structure of the Izu-Suruga Bay Area, Report of the Coordinating Comittee for Earthquake Prediction, Vol. 16, 1976, pp. 105-107 (in Japanese).

14) Research Group for Aftershocks: Observation of the Main and Aftershocks of the Earthquake off the Izu Peninsula, 1974, Report on the 1974 Earthquake off the Izu Peninsula, 1975, pp. 11-19 (in Japanese).

15) Utsu, T.: Detection of a Domain of Decreased P-Velocity prior to an Earthquake, Zisin, Ser. II, Vol. 28, 1975, pp. 435-448 (in Japanese with English abstract).